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Computer-Based Methodology For System Development

Site Production And Reduction System

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Computer-Based Methodology For System Development: Site Production And Reduction System*

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1.0 Introduction

Consider systems as synthetic organisms, isomorphic to true organisms. Systems develop, grow, learn, decay, and die. For man-machine systems to develop they must learn. Training and exercise are essential. System development requires both problem input tools to stimulate exercise and evaluation techniques to provide feedback. For system learning to occur a methodological integrity including problem input preparation and system evaluation must be built into system design.

Systems have long been looked at by engineers from the "black box" frame of reference (4). The classic block diagram shows inputs entering and outputs leaving the "box." The contents of the "box" become the functional relationship between input and output. A mathematical relationship called a transfer function describes the activity that goes on within the "black box." (See Figure 1.)

Communications theorists and cyberneticians have considered communication channels to be descriptive of systems. An information source transmits a message to a destination. (See Figure 1.) During this process events may occur and processes may operate which affect the contents of the message. However, the accuracy of the transmitted message, not the adaptability of the system, interests communications theorists. An altered message is to be studied and corrected, not desired.

Communication systems are described as possessing entropy, the quality leading to disorganization and system degradation. Physical information is defined as negative entropy. Entropy becomes a critical construct relating engineering theory to cybernetics. Rothstein writes, "We now consider another generalization of the entropy concept which makes precise the concept of organization. It turns out that organization is essentially a negative entropy just as information is. We shall apply this to system engineering design and show that its general philosophy becomes the same as that of communication system design." (6, p.34)

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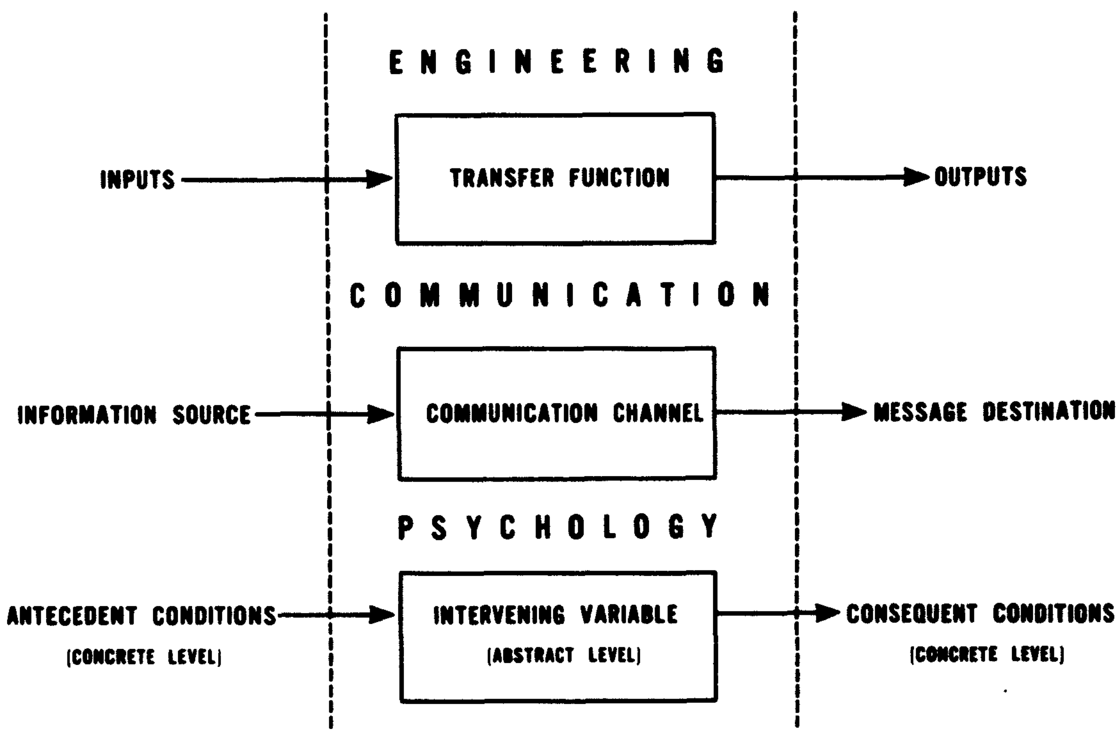

FIGURE 1. PARADIGMS USED IN ENGINEERING, COMMUNICATION, AND PSYCHOLOGY FOR THE STUDY OF SYSTEMS.

Looking at systems from the communications point of view, much happens within a system--either intended occurrences such as transmitted messages or phenomena relative to systems per se such as noise or entropy. Engineers assume something occurs within the "black box," but they show relatively little concern about the contents of the box so long as a mathematical transfer function accurately and consistently describes the input-output relationship.

Now let us look at systems such as living organisms from the psychologist's perspective. Using Bridgman's (1) operational approach, a familiar paradigm proves descriptive of much psychological methodology. Psychologists describe the behavior of living organisms in terms of intervening variables (the abstract level) defined and anchored into the real world (the concrete level) by antecedent conditions and consequent conditions. Accustomed to studying living organisms, psychologists have built whole theories of behavior (5, 7) upon this simple methodological approach. Concepts of growth and development, sensation, perception, concept formation, learning and motivation have all been studied using this paradigm. We see similarities between the approaches of the engineer, the cybernetician, and the psychologist. Inputs, information sources, and antecedent conditions look amazingly similar. All have a temporal, causal relationship to "black boxes," communication channels, or intervening variables. Similarly, outputs, message destinations, and consequent conditions look alike. They all result from activities occurring in an abstract entity.

Following Bridgman's logic (1), if the operations performed by engineers and cyberneticians in studying systems are like those performed by psychologists studying living organisms, then the constructs—transfer functions, communication channels, and intervening variables—are equivalent. Systems and living organisms can be considered operational equivalents. The wealth of theoretical insight into the behavior of organisms developed by psychologists can be logically applied to the study of systems. Properties exhibited by living organisms can be logically attributed to the synthetic organisms we call systems. And with proper translation, theoretical constructs developed by engineers and cyberneticians can be related to psychological constructs. This paper describes a computer-based methodology which uses such interdisciplinary translation.

2.0 Biological Model for Systems Thought

Following the logic we have presented, let us consider a system as a synthetic organism. In the volume Psychological Principles of System Development Kennedy writes, "When men and machines are assembled into a particular operational system, the assembly exhibits development, involving stages similar to birth (test in the operational environment), infancy (initial operational capability), maturity (full operation in relation to other systems), and senescence (phasing out for obsolesence). Possibly the term system life cycle might help in distinguishing these developmental processes in man-machine systems from their analogs in the individual biological organism." Here a longituidinal or genetic biological model has been applied to systems thought.

We propose to go a step further. Let us lean upon another biological model, the nervous system, for new insight into the functioning of systems. The nervous system provides the primary communication network in the living organism. The peripheral nervous system may be divided into afferent and efferent portions. The central nervous system provides organization and direction. The nervous system makes possible the higher order, the "human-like" behaviors which organisms exhibit.

For the synthetic organism which we call a system to exhibit the property called learning, system designers must build components analagous to the nervous system into the system. In order to do this, system designers must first decide what indispensable functions the nervous system provides living organisms in order that learning may take place.

The nervous system provides the mechanism which permits a living organism's behavior to be consequential. The efferent function becomes evaluative when related to the afferent function. Sensation and perception of the consequences of behavior, cognitively integrated, produce the capability for behavior modification. We call this learning. The nervous system provides the mechanism for feedback (knowledge of results). And feedback (knowledge of results) is the essential operational characteristic for learning to take place.

In The Human Use of Human Beings Wiener writes "...feedback is a method of controlling a system by reinserting into it the results of its past performance. If these results are merely used as numerical data for the criticism of the system and its regulation, we have the simple feedback of the control engineers. If, however, the information which proceeds backward from the performance is able to change the general method and pattern of performance, we have a process which may well be called learning." (8, p. 61) In order to build a system in which learning can occur, feedback capability must be built in by the system designers. The efferent subsystem must conceptually and functionally tie back into the afferent subsystem. When this feedback capability is built into a system by its designers, the system contains the development potential to exhibit that which psychologists call learning.

3.0 Biological Modeled Computer-Based System

Just as biological organisms constantly change, systems, synthetic organisms, also exist in a constant state of flux. Change occurs rapidly, making short lead time for preparation of training tools and feedback critical. As systems grow, complexity increases exponentially. Lead time for traditional methods of problem input generation and system evaluation becomes proportionally longer. Computer technology makes possible a solution to the problem.

The Site Production and Reduction System (SPARS) provides support for System Training in a large man-machine air defense system, the Semi-Automatic Ground Environment system (SAGE). To be effective, air defense components must be

integrated into a comprehensive system. "A system was required which would 1) maintain a complete, up-to-date picture of the air and ground situations over wide areas of the country, 2) control modern weapons rapidly and accurately, and 3) present filtered pictures of the air and weapons situations to the Air Force personnel who conduct the air battle." (2, p. 148)

In order to cope with training problems in a large-scale air defense system, a computer program system, the Site Production and Reduction System (SPARS), was developed to be operated by non-programmer personnel. SPARS requires minimum technical knowledge for operation. Symbolic, procedure-oriented computer languages are not required. The user communicates directly with the computer in everyday English phraseology. The computer provides tailored problem inputs with short lead time. The computer analyzes data for system evaluation. The system design combines problem generation and data reduction into an integral computer system.

In a complex air defense system like SAGE where failure in the real world becomes unthinkable, System Training using simulation techniques must be the vehicle for system learning. Reasoning from the biological model, for system learning to occur an afferent subsystem for simulation input preparation must be conceptually and functionally related to an efferent, evaluative subsystem. The capability for feedback must be built into the system. SPARS is an example of a computer program system built to incorporate such a biological model. The interplay between the afferent and the efferent subsystems becomes the powerful, potentially automatic training innovation introduced by SPARS. Engineers call systems exhibiting feedback capability control systems. Let us call a computer program system which incorporates feedback capability a training control complex.

SPARS was envisioned as a training control complex in which output, data reduction and analysis (the efferent subsystem), is used not only for immediate feedback to air defense crews being trained but also becomes an integral part of input, future problem design (the afferent subsystem). Cognitive integration takes place within the air defense system being trained.

4.0 <u>SPARS Afferent Subsystem (Exercise)</u>

Let us look operationally at the afferent subsystem in SPARS. Since this subsystem must make possible desired system behavior, that is, exercise the system being trained, let us call the afferent subsystem the exercise subsystem. An exercise subsystem is a serially input and output task-oriented subsystem. As a functional subsystem directed toward problem input tape and aids production, it has a goal, a desired output; it must perform a job. The job which the SPARS exercise subsystem performs may be broken down into five functional modules.

a. <u>Flight Generation</u>. Problem input tapes capable of producing simulated radar and symbolic display data for System Training Missions

are produced by the SPARS flight generation functional module. Flight specifications are fed to the computer via Hollerith cards. Critical occurrences, called stress events in SPARS, which are designed to evaluate system behavior are specified by problem designers as a part of input preparation. Thus, automated evaluation is built into input preparation. Flight generation is accomplished by the simulation vehicle UNISIM, a computer program system independent of but internally interfaced with SPARS.

b. Noise. An automated method for obtaining background noise (clutter) in a problem input tape is provided in the SPARS noise generation functional module.

c. Tape Modification. When problem input tapes require change, for example, updating, correction, or format conversion, the SPARS tape modification functional module makes manipulation possible.

d. Quality Control. Information about the contents of the problem input tape, its accuracy and consistency, may be verified by means of the SPARS quality control functional module.

e. Aids. System Training Mission aids are produced by the SPARS aids functional module. Training aid listings of certain events which occur on problem input tapes are automatically produced, thus eliminating hand-scripting of these aids.

All of the SPARS functional modules described above are essential input preparations to provide suitable simulation tools for air defense System Training Missions. These functional modules must be operated as a necessary antecedent condition to exercising the air defense system. Exercise is the essential requirement for system learning to occur. Therefore, we designate these five functional modules the exercise subsystem.

5.0 SPARS Efferent Subsystem (Evaluation)

In the same way that exercise subsystems are task-oriented functional systems, efferent subsystems -- evaluation subsystems -- also have a goal. They, too, are serially input and output subsystems. Designed to perform a single function, that is, evaluate system performance during the System Training Mission, the SPARS evaluation subsystem at present contains a single functional module divided into three parts.

a. Synoptic Processors. Three computer programs compose the SPARS synoptic processing functional module. One computer program reduces the data recorded during the System Training Mission and provides a time-oriented printout. Another yields evaluative and diagnostic information about the performance of SAGE Air Surveillance crews.

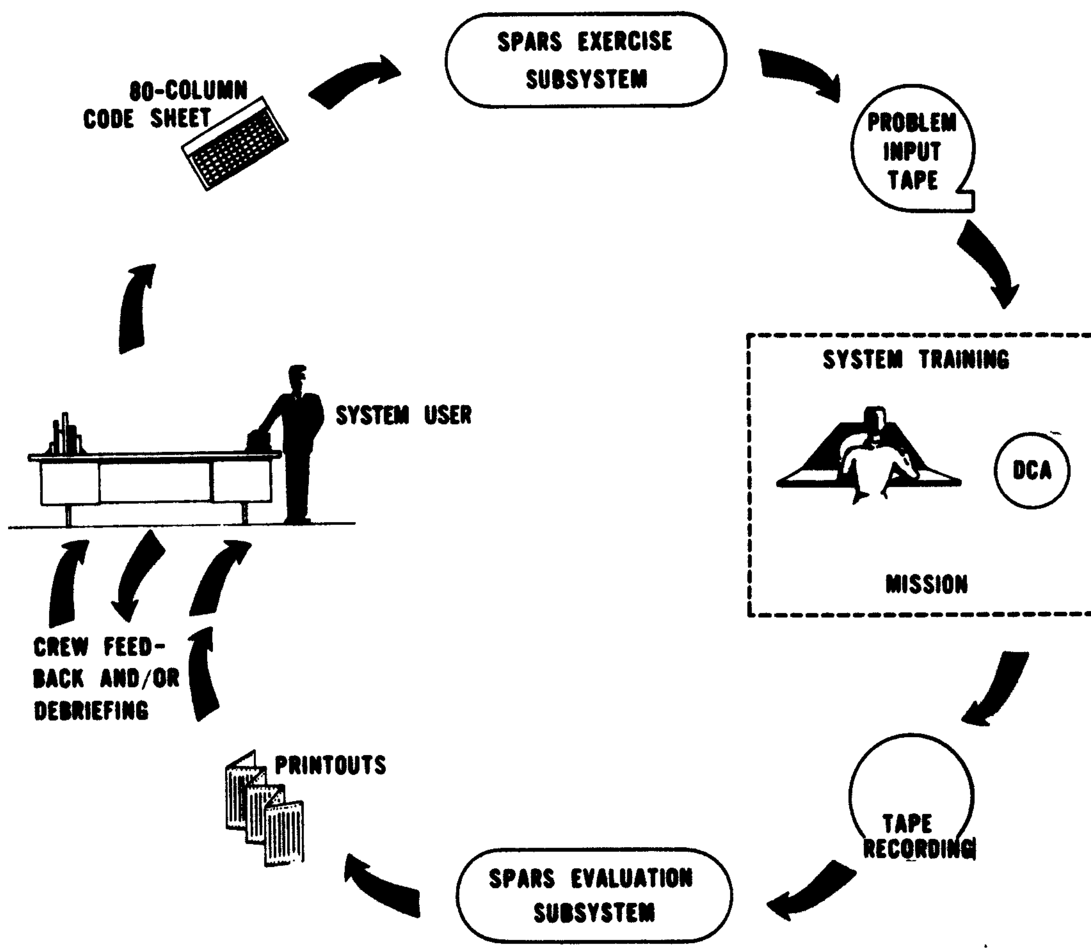

FIGURE 2. THE SPARS TRAINING CONTROL COMPLEX WITH LIMITED INTERFACE REPRESENTATION.

While the third, a special data processor, produces a weapons summary output which provides a concise report of the results of weapons commitment.

6.0 SPARS as a Training Control Complex

SPARS performs a training function. It provides a computer-based methodology designed so that system learning may occur. Feedback is an integral part of the conceptual design. SPARS contains an exercise subsystem and an evaluation subsystem, and operates in conjunction with air defense crews and other computer systems as a training control complex. Figure 2 illustrates this principle.

The system user formulates a training problem and communicates with SPARS by scripting his inputs on an 80-column code sheet. This code sheet then becomes the input to the SPARS exercise subsystem. (Human beings ancillary to Electronic Accounting Machine (EAM) and computer operation are ignored in this broad analysis). The output of SPARS, the problem input tape, becomes the input to the man-machine complex called the System Training Mission. The output of the System Training Mission, a recording tape, becomes the input to the SPARS evaluation subsystem. The system user obtains the SPARS output in the form of printouts which he uses for crew feedback and/or debriefing. Stress events determined by the exercise system are an axillary input to the synoptic processors. These stress events are categorized. The evaluation performed is subdivided by stress categories which serve as an indication to guide the emphasis for following problems. <u>For maximal training effectiveness, for system learning to occur, the system user must analyze SPARS output and incorporate his findings into the formulation of the specifications for his next problem input tape</u>. The formulation of SPARS as a training control complex permits this computer-based system to provide a methodology for system development, where development is specifically defined as system learning.

7.0 Summary and Conclusions

1. Engineers, cyberneticians, and psychologists operationally use similar constructs in the study of systems and living organisms. If the operations performed in the study of constructs are equivalent, then the constructs themselves may be assumed equivalent. Properties exhibited by and methods used for studying living organisms can logically be applied to the study of systems.

2. For systems, synthetic organisms, to learn as do their living counterparts, components similar to the nervous system must be built into them. A biologically modeled system capable of learning requires an afferent subsystem, a locus for cognitive integration, an efferent subsystem, and an integral provision for feedback.

3. As a computer program system SPARS contains an afferent or exercise subsystem and an efferent or evaluation subsystem. Looking at SPARS as a training control complex, the afferent and efferent subsystems are related circularly to the locus for cognitive integration (the air defense System Training Mission) and to each other by means of system user feedback channels. In the larger sense SPARS functions as a training control complex. Using the design methodology developed in SPARS, synthetic organisms (systems) may be provided the capability to learn. This capability possesses the potential for automation. Thus SPARS is in the forefront of technological advance by providing a computer-based methodology for system development.

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Reports that engineers, cyberneticians, and psychologists operationally use similar constructs in the study of

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systems and living organisms. Also reports that if the operations performed in the study of constructs are equivalent, then the constructs may be assumed equivalent. States that the properties exhibited by and methods used for studying living organisms can logically be applied to the study of systems. Also states that components similar to the nervous system must be built into systems, synthetic organisms, so that they can learn as do their living counterparts.

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